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(54) Inlet Cowl for Supersonic Aircraft Engine

(57) An inlet cowl for a two-dimensional inlet to a gas turbine engine, effective for eliminating the region of cowl-lip induced boundary layer separation at the face of the engine and for providing an auxiliary flow of air to the engine during take-off, includes a lower portion 4 comprising a forward cowl section 9 having a cowl lip 8, an aft cowl section 10 spaced downstream and apart from the forward cowl section, and a cowl door 11 between and immediately adjacent the forward and aft cowl sections. When pivoted to an open position, the door extends into the inlet, thereby forming a termination point for the region of boundary layer separation 21 while also defining an auxiliary air inlet 15 between its lower surface and the aft cowl section.

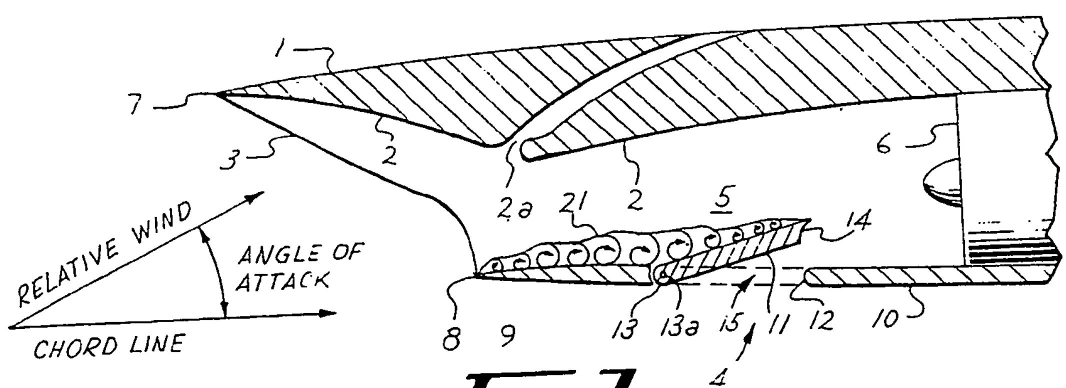

Fig 2

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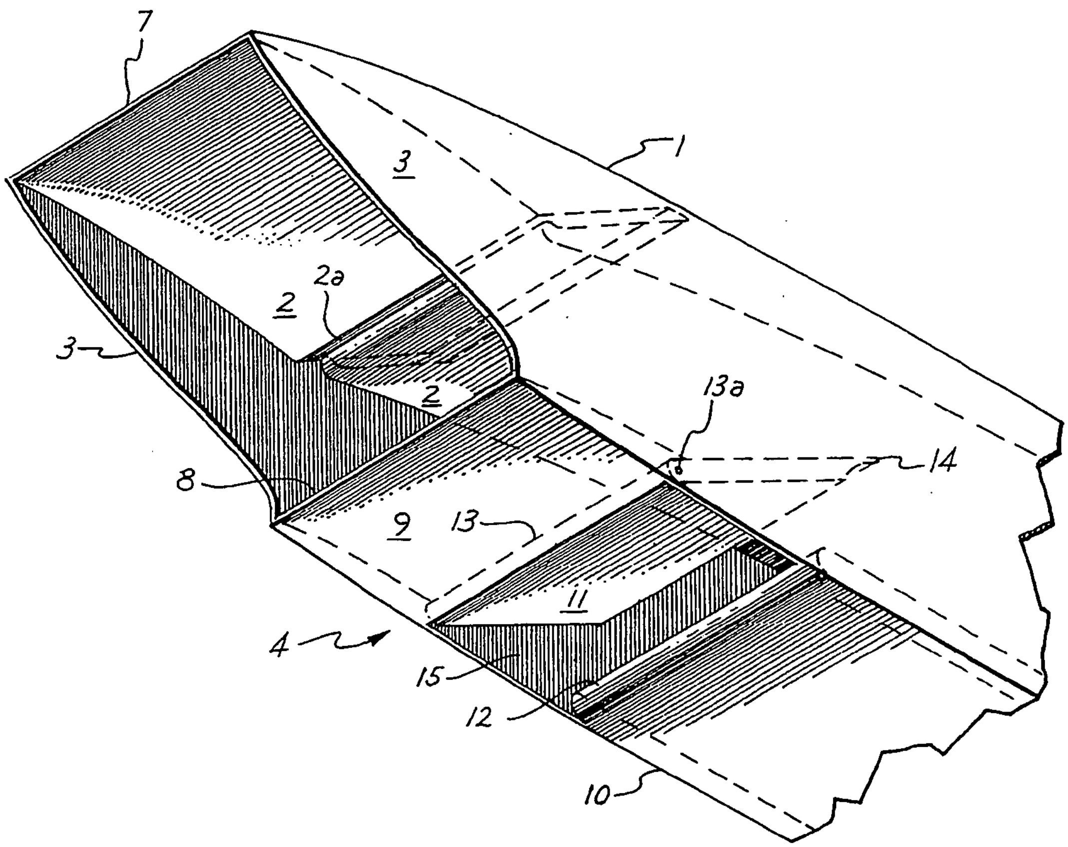

Fig 1

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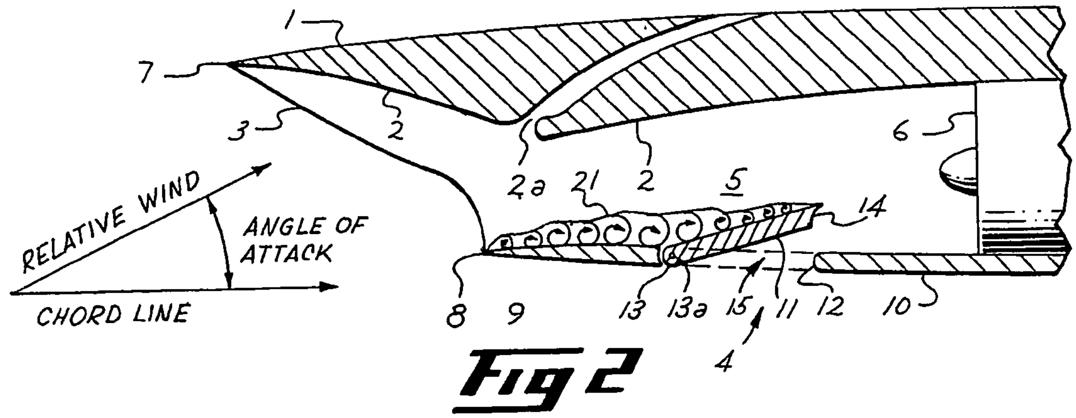

Fig 2

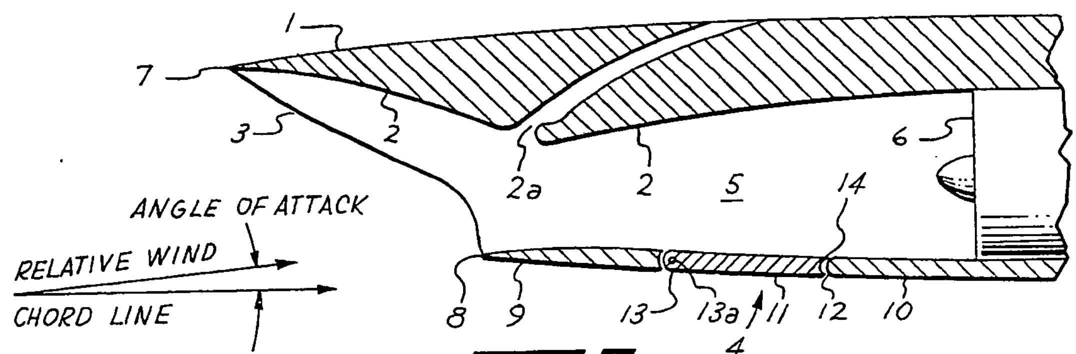

Fig 3

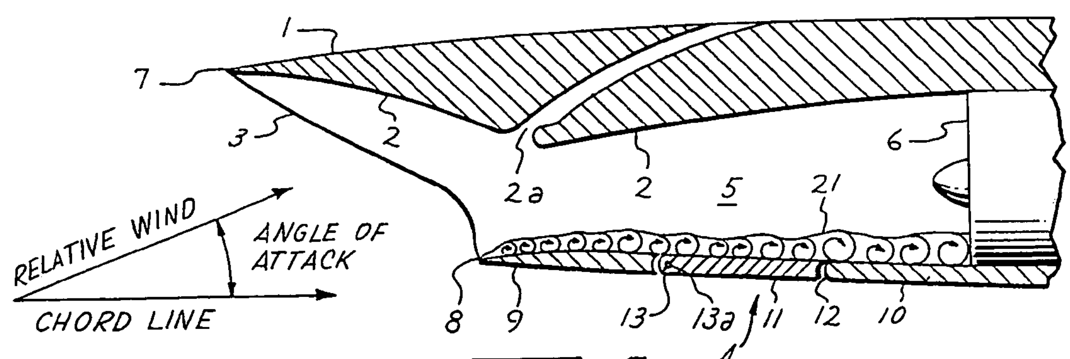

Fig 4

SPECIFICATION
Inlet Cowl for a Two-Dimensional Inlet

This invention relates to inlets to gas turbine engines and particularly to a new and improved lower portion of an inlet cowl for a two-dimensional inlet which is effective for eliminating the region of cowl lip induced boundary layer separation at the face of the engine during flight at high angles of attack.

2. Description of the Prior Art

Aircraft which are designed to fly at super-sonic speeds must have engine inlets which slow the air within the inlet to a subsonic speed before it enters the engine. This is accomplished by constructing the inlet such that it properly positions the pattern of shock waves, created in and around the inlet during super-sonic flight, to effectuate a decrease in airstream velocity.

One type of inlet which, when used on a super-sonic aircraft, is effective for providing a subsonic flow of air to the engine by properly positioning shock wave patterns is the rectangular cross-section, or two-dimensional, inlet. The inlet is defined by the lower portion of the inlet cowl, a ramp or series of ramp sections and two side plates. These components have sharp leading edges to facilitate shock wave pattern control and minimize aerodynamic drag.

Problems can arise, however, when a super-sonic aircraft flies at transonic, and particularly at subsonic speeds. The wings on a supersonic aircraft develop optimum lift at supersonic speeds. When the aircraft flies at lower speeds, it must operate at a relatively high angle of attack to maintain sufficient lift, especially during maneuvering flight conditions. Angle of attack is the angle between the chord line of the aircraft wing and the relative wind. A chord line is a line drawn between the leading and the trailing edges of the wing. The relative wind is the resultant vector of the aircraft velocity vector and the actual wind vector. Since the engine inlets on such a supersonic aircraft are substantially aligned with the chord line of the aircraft, when the aircraft operates at a high angle of attack, the inlets are therefore also disposed at a high angle of attack.

To more fully explain the problems which can arise when an inlet is operated at a high angle of attack, a short discussion of boundary layer theory is required. A boundary layer of air develops over the surface of a body whenever air flows across that surface. The boundary layer results from the viscosity of the air and the skin friction of the surface. The velocity and pressure of the air within the boundary layer vary with the distance from the surface, but at all points within the boundary layer, the velocity of the air is less than that of the free stream air, that is, the air outside of the boundary layer. In fact, the air within the boundary layer and immediately adjacent the surface of the body is slowed to a relative velocity of near zero. Normally, the boundary layer is relatively shallow and remains close to the surface of the body. However, when the pressure distribution across the surface of the body reaches or exceeds a certain value, the boundary layer separates, that is, it grows outwardly from the surface. The region between the outer limit of the separated boundary layer and the surface of the body is the "region of boundary layer separation". Within this region, the air is unstable, with varying velocities, pressures, and directions of flow.

A region of boundary layer separation can develop within a two-dimensional inlet to a gas turbine engine, particularly when the inlet has a sharp cowl lip on the lower portion of the cowl. Such sharp cowl lips are common on two-dimensional inlets for supersonic aircraft. When the inlet is at a high angle of attack, the pressure distribution across the inner surface of the lower cowl portion of the inlet is sufficient to cause the boundary layer along the inner surface to separate. Since the shape of the cowl lip is an important factor in the pressure distribution within the inlet, the resultant separated region is known in the art as a "region of cowl-lip induced boundary layer separation". This undesirable region of cowl-lip induced boundary layer separation extends through the inlet to the forward face of the engine. That portion of the engine face covered by the region of boundary layer separation is effectively blocked off from receiving the higher velocity free stream air, that is, the air within the inlet but outside of the boundary layer, which the engine requires to operate efficiently.

One manner of reducing the impact of the region of cowl-lip induced boundary layer separation at the face of the engine is to increase the length of the inlet. A longer inlet gives the free-stream high velocity air a greater opportunity to mix with and reduce the adverse effect of the separated boundary layer. However, the increased length of the inlet results in greater weight and higher cost. Further, the longer inlet is of no benefit during supersonic flight, as the modification is permanent, there being no practical way of shortening the inlet during that phase of flight.

Another approach available to reduce the region of cowl-lip induced boundary layer separation is to modify the shape of the leading edge of the lower cowl portion, or cowl-lip, of the inlet to make it less sharp and more contoured. A contoured cowl-lip would allow the air to flow over its edge rather than being blocked by it and would thereby decrease the chance of the boundary layer separating. However, this modification adversely affects the shock pattern control capability and increases the aerodynamic drag of the inlet during supersonic flight, where a sharp cowl-lip is essential.

Another problem is encountered with inlets during take-off. In view of the fact that an inlet for a supersonic aircraft is ordinarily designed to control shock wave patterns and to reduce the velocity of the air within it, the volume of air

flowing through the inlet at the very low speeds during take-off is often insufficient to achieve required engine thrust levels. Although previously constructed inlets for supersonic aircraft have incorporated devices to augment the amount of air available to the engine during take-off, none are known to have utilized that same device in a two-dimensional inlet to control the region of cowl-lip induced boundary layer separation which occurs at high angles of attack.

The present invention, in accordance with one embodiment thereof, comprises an inlet cowl for a two-dimensional inlet to a gas turbine engine, the cowl having a lower portion which includes a forward cowl section, an aft cowl section spaced apart and downstream from the forward cowl section, and means between the forward and aft cowl sections for eliminating the region of cowl-lip induced boundary layer separation at the face of the engine.

In one particular embodiment of the invention, the means for eliminating the region of cowl-lip induced boundary layer separation comprises a cowl door. The cowl door preferably pivots about its upstream edge into an open position extending into the air stream within the inlet and thus forms a termination point for the region of cowl-lip induced boundary layer separation occurring over the forward cowl section at high angles of attack. When the door is opened, an auxiliary air inlet is defined between the open door and the aft cowl section providing a flow of high pressure, high velocity air therethrough to the engine during flight at high angles of attack and during take-off. The downstream end of the door can be shaped such that when the door is closed, it engages the forward edge of the aft cowl section. The forward cowl section preferably includes a cowl-lip defining a sharp edge, and the aft cowl section preferably includes a forward edge having a contoured shape.

Figure 1 is a fragmentary front perspective view of the two-dimensional inlet incorporating the features of the present invention.

Figure 2 is a fragmentary cross-sectional view of a two-dimensional inlet disposed at a relatively high angle of attack and showing the cowl door in its open position and establishing an auxiliary air inlet.

Figure 3 is a fragmentary cross-sectional view of the two-dimensional inlet disposed at a low angle of attack and showing the cowl door closed.

Figure 4 is a fragmentary cross-sectional view of the two-dimensional inlet disposed at a relatively high angle of attack and with the cowl door closed.

Turning now to a consideration of the drawing, and in particular to Figure 1, there is shown an improved inlet cowl for a two-dimensional inlet to a gas turbine engine, constructed in accordance with one embodiment of the present invention.

As seen in Figures 1 and 2, the inlet or opening enclosed by the inlet cowl 1 is two-dimensional and includes a ramp 2, which can have a bleed slot 2a, a pair of laterally spaced side plates 3, and a lower cowl portion generally designated 4. By "two-dimensional", it is meant that the inlet has a generally rectangular cross-sectional front opening. The inlet cavity 5 is the hollow region bounded by the ramp 2, the side plates 3, and the lower cowl portion 4 which, as described below, comprises several constituent sections. The ramp 2 and the side plates 3 comprise inner surfaces of the inlet cowl 1. However, either side plate 3 can be integral with the aircraft fuselage when the inlet is mounted on the side of the fuselage.

The function of the inlet is to provide a subsonic flow of air, at uniform velocity and pressure, to the engine 6, even though the aircraft may be flying at a supersonic speed. As air enters the inlet at a supersonic speed, shock waves are created within and around the inlet. The inlet is geometrically designed to slow the air and result in the weakest practical combination of shock waves in order to minimize energy losses. The shapes of the ramp 2 and the lower cowl portion 4 and their relation to each other are such as to control the shock wave pattern in a manner which minimizes such energy losses. Various shapes of the ramp and cowl can be successfully utilized with the present invention and the particular shapes shown in Figure 2 are only representative. For example, the ramp 2 can comprise several movable ramp sections allowing the shape of the ramp to be changed. The ramp 2 can include a bleed slot 2a for bleeding off air in excess of that required by the engine. The tip 7 of the ramp 2 and the cowl-lip 8 of the lower cowl portion 4 preferably define sharp edges to further improve inlet performance in supersonic conditions.

The lower cowl portion 4 comprises a forward cowl section 9, an aft cowl section 10 spaced apart and downstream from the forward cowl section, and means, such as a cowl door 11, between the forward and aft cowl sections which, as will be described shortly, is effective for eliminating the region of cowl-lip induced boundary layer separation at the face of the engine 6.

In the preferred embodiment shown in Figures 1 and 2, the front edge, or cowl lip 8, of the forward cowl section defines a sharp edge. The forward edge 12 of the aft cowl section 10 has a contoured shape for reasons to be described hereinafter. The cowl door 11 is between and immediately adjacent the forward and aft cowl sections 9 and 10, extends the width of the lower cowl portion 4, and preferably has a thickness which is approximately the same as that of the forward and aft cowl sections. The door 11 is pivotable about its upstream edge 13 as, for example, by a hinge 13a extending within a concave recess defined by the downstream edge of the forward cowl section 9. When pivoted to an open position as shown in Figure 2, the downstream end 14 of the door 11 extends into the inlet cavity 5. When this pivoted or opened, an auxiliary air inlet 15 is defined and is effective in a

manner hereinafter described in detail. The downstream end 14 of the door is suitably shaped such that it forms a seal with the aft cowl section 10 when the door 11 is closed. This arrangement not only inhibits air leakage between the door 11 and the aft cowl section 10, but also presents a smooth inner surface to air flowing through the inlet. An example of a suitable shape for the downstream end 14 of the door 11 is shown in Figure 2 as a pointed extension contoured to conform to the shape of the forward edge 12 of the aft cowl section 10.

Any suitable means can be utilized for opening and closing the door 11. Although none is shown in the drawing, examples of such suitable means are a spring arrangement, whereby the door 11 automatically opens when the pressure on its lower side exceeds the bias of the springs, and a hydraulic or electrically operated actuator, whereby the door 11 is opened when a preselected parameter, such as angle of attack, has been exceeded.

The forward edge 12 of the aft cowl section 10 is sealably engaged by the downstream end 14 of the door 11 when the door is closed. When the door 11 is opened, the forward edge 12 becomes a lip for the auxiliary air inlet 15. The forward edge 12 has a suitably contoured shape, that is, a shape which is generally curved rather than being sharp as is the cowl lip 8. The most suitable contour shape for the forward edge 12 is determined by the particular flight characteristics to which the inlet will be normally subjected, such as expected maximum angle of attack and aircraft speed.

The improved inlet cowl of the present invention functions as follows. The door 11 remains in its closed position when the aircraft is at a low angle of attack. This can be seen in Figure 3. Angle of attack is defined as the angle between the chord line of an aircraft wing and the relative wind. A chord line is a line drawn between the leading and trailing edges of the wing. The relative wind is the resultant vector of the aircraft velocity vector and the actual wind vector. The chord line of an aircraft on which the inlet is mounted is approximately parallel to the lower cowl portion 4 of that inlet. Therefore, at low angles of attack, the air, or relative wing, entering the inlet, flows generally parallel to the lower cowl portion 4. The resultant pressure distribution over the inner surface of the lower cowl portion 4 is such that boundary layer separation will not occur and the boundary layer will remain relatively shallow and close to the inner surface of the lower cowl portion. Thus, the face of the engine 6 will not be blocked by any region of boundary layer separation, and all of the air in the inlet will reach the face of the engine at approximately the same velocity and pressure.

However, as can be seen in Figure 4, at a high angle of attack, the relative wind does not flow parallel to the lower cowl portion 4. Instead, it enters the inlet at an angle. Due to this angle and because the cowl lip is a sharp edge, the pressure distribution over the inner surface of the lower cowl portion 4 is such that a region of cowl-lip induced boundary layer separation develops. The upper limit of the region of the separated boundary layer is denoted in Figures 2 and 4 as the line 21. The air within the region of cowl-lip induced boundary layer separation has a velocity less than that of the free stream air within the inlet cavity 5 and outside of the boundary layer, and is of differing pressure and direction of flow. As is schematically shown in Figure 4, the region of cowl-lip induced boundary layer separation extends to the face of the engine 6 itself and effectively blocks off a portion of the engine from receiving a steady high velocity flow of air from the inlet. Thus, the region of cowl-lip induced boundary layer separation has the undesirable effect of reducing engine efficiency, and it can induce engine surge or stall.

Changing the shape of the cowl lip 8 from being a sharp edge to a contoured edge would reduce the thickness of or might eliminate the region of cowl-lip induced boundary layer separation by permitting the air stream to flow over the contoured edge and closer to the inner surface of the lower cowl portion 4. However, this change is undesirable because it would increase drag and, if the two-dimensional inlet is on a supersonic aircraft, a sharp cowl lip is required to control shock patterns.

Utilization of the present invention not only effectively eliminates the region of cowl-lip induced boundary layer separation at the face of the engine 6, but also permits the sharp edge of the cowl lip 8 to be retained.

Referring again to Figure 2, at high angles of attack, the door 11 opens. The region of cowl-lip induced boundary layer separation, which continues to occur over the forward cowl section 9, terminates at the upper surface of the door 11. With the door 11 open, the unstable air within the region of cowl-lip induced boundary layer separation over the forward cowl section 9, remains trapped upstream of the door. Air within but near the outer limit of the region of boundary layer separation is accelerated by the upper surface of the door 11 as the air passes over it to the velocity of the free stream air outside of the region of boundary layer separation. The axial length of the door 11 is determined by the thickness of the region of cowl-lip induced boundary layer separation which is expected to occur. The thicker the expected region, the greater the required extension of the door into the cavity 5. The angle to which the door opens is also determined by the expected flight conditions, such as angle of attack and airspeed, inasmuch as the lower surface of the door together with the contour of the forward edge 12 guides the flow of air through the auxiliary air inlet 15 and over the inner surface of the aft cowl section 10, while the upper surface of the door accelerates the air within and near the outer limit of the region of boundary layer separation. The door 11 can also

be constructed such that the angle to which it opens varies with the angle of attack.

When the door 11 opens, an auxiliary air inlet 15 is defined between the lower surface of the door 11 and the forward edge 12 of the aft cowl section 10. The forward edge 12 becomes a lip for the auxiliary air inlet 15. Inasmuch as the forward edge 12 is contoured, the air which enters through the auxiliary air inlet 15 flows smoothly over the contour and close to the inner surface of the aft cowl section 10. As a result, the pressure distribution over the aft cowl section 10 is such that boundary layer separation over the aft cowl section is prevented. The combined free stream air flow entering through the rectangular, two-dimensional inlet and the auxiliary flow of air entering through the auxiliary air inlet presents air flow at the face of the engine 6 of substantially uniform pressure and velocity and essentially devoid of any region of cowl-lip induced boundary layer separation. When the angle of attack is reduced sufficiently to prevent boundary layer separation over the forward cowl section 9, the door 11 is closed.

If desired, the door 11 can be constructed so as to open during take-off in order to augment the supply of air to the engine. When used for this purpose, an auxiliary flow of air enters the inlet through the auxiliary air inlet 15 in the same manner described previously.

The opening of the door can be limited to flight speeds in the subsonic and transonic ranges in order to avoid loss of shock pattern control in the supersonic range. In addition, the improved inlet cowl of this invention can be satisfactorily utilized on a two-dimensional subsonic, as well as supersonic, inlet.

Further, this invention is effective independent of the overall length of the inlet. The entire inlet, including the lower cowl portion 4, can thus be reduced in length, with a corresponding reduction in weight and cost, and the invention will still eliminate the region of cowl-lip induced boundary layer separation at the face of the engine 6.

Claims

1. An improved inlet cowl for a two-dimensional inlet to a gas turbine engine, said cowl including a lower portion comprising:

(a) a forward cowl section including a cowl lip;

(b) an aft cowl section spaced downstream and apart from said forward cowl section; and

(c) means between said forward and aft cowl sections effective for eliminating cowl-lip induced boundary layer separation at the face of the engine.

2. The improved inlet cowl of claim 1, wherein said means for eliminating cowl-lip induced boundary layer separation comprises a cowl door between and immediately adjacent said forward and aft cowl sections.

3. The improved inlet cowl of claim 2, wherein said door is pivotable about its upstream edge for opening into the inlet and thereby defining an auxiliary air inlet for introducing an auxiliary flow of air into said inlet cowl.

4. The improved inlet cowl of claim 1, wherein said cowl lip defines a sharp edge.

5. The improved inlet cowl of claim 1, wherein said aft cowl section has a contoured forward edge.

6. The improved inlet cowl of claim 3, wherein said aft cowl section is arranged to be engaged by said door when said door is closed.

7. The improved inlet cowl of claim 3, wherein the downstream edge of said forward cowl section defines a concave recess for receiving the upstream edge of said door.

8. The improved inlet cowl of claim 3, wherein said door extends the entire width of said cowl lower portion.

9. The improved inlet cowl of claim 3, wherein the thickness of said door is substantially the same as the thickness of the forward and aft cowl sections.

10. An improved inlet cowl for a two-dimensional inlet to a gas turbine engine, said cowl including a lower portion comprising:

(a) a forward cowl section including a cowl lip defining a sharp edge and a downstream edge defining a concave recess;

(b) an aft cowl section spaced downstream and apart from said forward cowl section and having a contoured forward edge; and

(c) a cowl door between and immediately adjacent said forward and aft cowl sections pivotable about its upstream edge for opening into the inlet and thereby defining an auxiliary air inlet for eliminating cowl-lip induced boundary layer separation at the face of the engine and providing an auxiliary flow of air into said inlet cowl, said concave recess in said forward cowl section receiving the upstream edge of said door, said door engaging the contoured forward edge of said aft cowl section when said door is closed, and said door extending the entire width of said cowl lower portion and having a thickness substantially the same as the thickness of said forward and aft cowl sections.

11. An inlet cowl substantially as hereinbefore described with reference to and as illustrated in the drawings.

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